

Engineering Sciences Accelerometers

Vibration-Induced Gas-Liquid Effects in Accelerometers

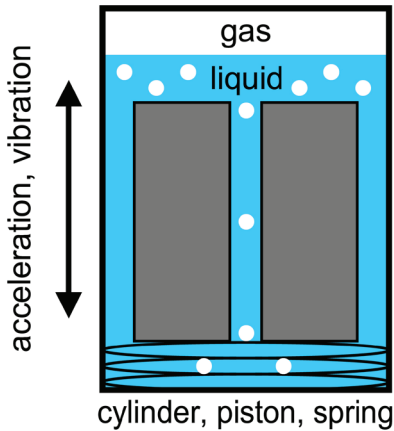


Figure 1: Schematic diagram of a liquid-filled mechanical accelerometer.

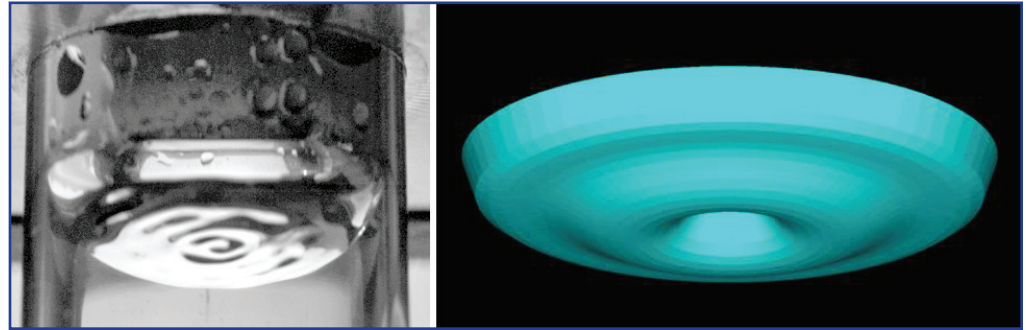


Figure 2: Vertically vibrating gas-liquid interface viewed from below. Left: Experiment where the liquid is contained in clear plastic cylinder and concentric waves appear on the bright circular free surface. Right: computer simulation.

Gas-liquid interactions in accelerometers experiencing vertical vibration can produce rich dynamical behavior.

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Sensing acceleration accurately is essential to Sandia's nuclear weapons mission. Accelerometers for these applications are typically mechanical rather than electronic and must function reliably when subjected to intense vibration environments (Figure 1). During vibration, the gas and liquid in accelerometers can interact to produce waves (see Figure 2) and bubbles that impact the accelerometer's dynamical behavior.

A mechanical accelerometer has several internal components that affect its dynamics (Figure 1). The *cylinder* is a closed housing that actually experiences the applied acceleration and vibration. The *piston* is a massive solid object that moves along the cylinder's axis in response to the applied acceleration. The *spring* prevents the piston from moving downward until gravity plus acceleration exceed the spring's preload force. The *liquid* is a viscous oil that is forced upward through the piston's flow passages as the piston moves downward, thereby damping the motion. The *gas* is mostly air and partly oil vapor and is included to account for the different thermal expansion of the liquid relative to the solid components

over the intended temperature range. Although not shown, *electrical contacts* produce friction, which also damps the piston motion.

Under certain conditions of vibration, the interaction of these components can cause the piston to move downward against the spring even when the spring is more than strong enough to support the piston in the absence of vibration. This unexpected dynamical behavior is related to the transport of gas from the headspace above the piston to the spring region below the piston. Anomalous piston motion has been conjectured to consist of four steps: (1) generation of waves on the gas-liquid interface; (2) production of bubbles by these surface waves; (3) the (counterintuitive) downward net motion of these bubbles; and (4) the downward net motion of the piston, which is caused by the gas distributions created by these downwardly moving bubbles.

Theoretical, computational, and experimental investigations are underway to understand each of these steps and how they combine to cause anomalous piston motion. The major focus has been the

vibration-induced generation and growth of waves on the gas-oil interface (References 1,2). In 1831, the famous British scientist Michael Faraday showed that waves form on a gas-liquid interface when the liquid layer is vibrated vertically at certain frequencies and amplitudes. This parametric wave instability, known technically as a period-doubling bifurcation, has been studied in the past for thin layers of low-viscosity liquids like water.

Figure 3 shows the results of the present theoretical and computational investigations for large depths of a high-viscosity oil. For a given vibration amplitude (254 microns), waves occur only within certain frequency bands (e.g., 18.5-20.7 Hz), with more waves observed as the frequency is increased. The theoretical and computational predictions for these instability bands are in excellent agreement, typically to within 0.1 Hz. Figure 4 shows similar experimental results in which the displacement amplitude is held constant at 250 microns while the frequency is increased from 120 Hz to 160 Hz. In accord with theory, the waves increase in number and strength as the frequency is increased. The experiments reveal additional features not yet investigated theoretically or computationally, namely long thin liquid jets, droplets formed by these jets pinching off, and cavities formed by these droplets impacting the gas-liquid interface (see Figure 5). Computations to investigate these additional flow features are underway.

Future efforts will focus on making more detailed comparisons between the experiments and the theoretical results for wave generation and the other three steps in the conjectured route to anomalous piston motion in accelerometers. Of particular interest is how strong vibrations can induce downward bubble motion and stabilize a gas pocket below the piston. Two gas pockets, one above the piston and the other below it, can act together as an extra spring that enhances the downward motions of the gas and the piston. The long-term goal of this investigation is a quantitative, predictive understanding of each step in this process and how these steps work together to produce anomalous piston motion in accelerometers.

References

1. A. M. Kraynik, L. Romero, J. R. Torczynski, C. F. Brooks, T. J. O'Hern, R. A. Jepsen, and G. L. Benavides, "The Effect of Dynamic Wetting on the Stability of a Gas-Liquid Interface Subjected to Vertical Oscillations," *Bulletin of the American Physical Society*, **54** (19), p. 48 (2009).
2. L. Romero, J. R. Torczynski, and A. M. Kraynik, "A Scaling Law near the Primary Resonance of the Quasi-Periodic Mathieu Equation," *Nonlinear Dynamics*, submitted in April (2010).

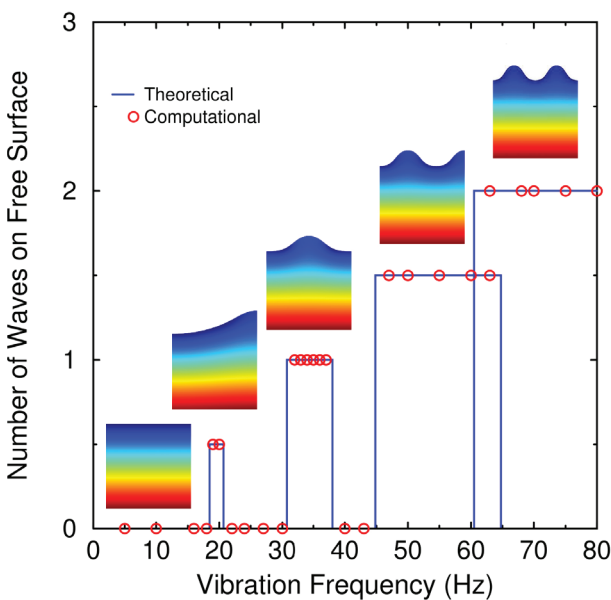


Figure 3: Number of waves on vertically vibrated gas-liquid interface.

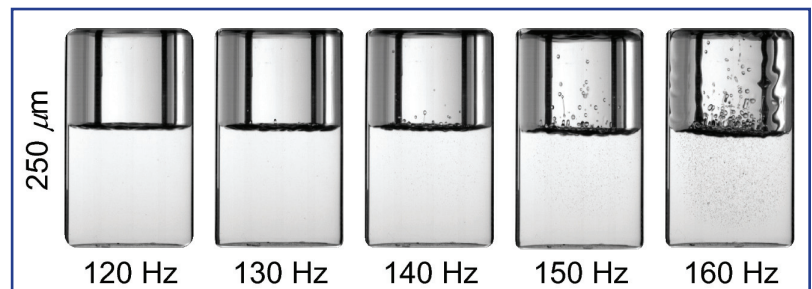


Figure 4: Increasing the frequency at fixed stroke increases the disturbance level.



Figure 5: Enlarged view of 160 Hz data in Fig. 4